

The invention in which an exclusive right is claimed is defined by the following:

1. A compact scanner, comprising:
  - (a) a waveguide that conveys light between a proximal and a distal end, said waveguide having an effective light source position proximate to the distal end;
  - (b) an optical component that is attached to the distal end of the waveguide, said optical component reducing a numerical aperture of the lensed waveguide; and
  - (c) an actuator for exciting a portion of the waveguide that is adjacent to the distal end and is cantilevered from the actuator to vibrate at a desired frequency and in a desired pattern, excitation of the portion of the waveguide that is cantilevered from the actuator causing a rotation to occur for scanning a region with light from the optical component.
2. The compact scanner of Claim 1, wherein excitation of the portion of the waveguide that is cantilevered from the actuator also causes a translation of a distal end of said portion to occur for scanning the region with the light from the optical component.
3. The compact scanner of Claim 2, wherein a portion of the region scanned as a result of the rotation is substantially greater than that scanned as a result of the translation.
4. The compact scanner of Claim 1, wherein the waveguide includes an effective light source, and wherein the optical component and the waveguide are configured so that a vibratory node of the waveguide is substantially coincident with a position of the effective light source.
5. The compact scanner of Claim 1, wherein the portion of the waveguide that is cantilevered from the actuator includes a region of substantially reduced cross-sectional area to more readily enable a lateral bending of said portion.
6. The compact scanner of Claim 1, wherein the optical component has a back focal point that is substantially coincident with a vibratory node of the waveguide.

7. The compact scanner of Claim 1, wherein the waveguide includes an effective light source, and wherein the optical component has a back focal point that is substantially coincident with a position of the effective light source.

8. The compact scanner of Claim 7, wherein light exiting the optical component travels in a substantially collimated path.

9. The compact scanner of Claim 1, wherein the optical component has a back focal point that is distal relative to the effective light source position.

10. The compact scanner of Claim 9, wherein light exiting the optical component travels in a convergent path.

11. The compact scanner of Claim 1, wherein the waveguide comprises an optical fiber.

12. The compact scanner of Claim 5, wherein the region of substantially reduced cross-sectional area is etched to reduce the cross-sectional area of said region relative to adjacent portions of the waveguide that are not reduced in cross-sectional area.

13. The compact scanner of Claim 12, wherein the optical component is fused to the distal end of the waveguide, where the waveguide is not substantially reduced in cross-sectional area.

14. The compact scanner of Claim 5, wherein the region of substantially reduced cross-sectional area has a desired nonlinear shape.

15. The compact scanner of Claim 1, wherein the effective light source position corresponds to a point proximate to the distal end of the lensed waveguide where the waveguide is no longer internally guiding light.

16. The compact scanner of Claim 1, further comprising a scan lens that is disposed between the optical component and the region being scanned, said scan lens optically modifying the light exiting the optical component and incident on the region being scanned.

17. The compact scanner of Claim 1, wherein the optical component comprises one of a ball lens, a drum lens, a graded index (GRIN) lens, and a diffractive optical element.

18. The compact scanner of Claim 1, wherein the optical component comprises a section of a multimode optical fiber.

19. The compact scanner of Claim 1, wherein the optical component has a back focal plane, further comprising a spacer for coupling the optical component to the distal end of the waveguide, said spacer being used to control a disposition of the vibratory node of the waveguide relative to the back focal plane of the optical component.

20. The compact scanner of Claim 1, wherein the actuator excites the portion of the waveguide that is cantilevered from the actuator to vibrate at a resonant frequency.

21. A method for fabricating a compact optical scanner for scanning a region, comprising the steps of:

(a) providing a waveguide through which light is guided between a proximal end and a distal end of the waveguide;

(b) attaching an optical component to the distal end of the waveguide, said optical component having a back focal plane;

(c) substantially reducing a cross-sectional area of a portion of the waveguide adjacent to the distal end, leaving the distal end of the waveguide where the optical component is attached unreduced in cross-sectional area; and

(d) coupling an actuator to the waveguide to vibrate the portion of waveguide that is reduced in cross-sectional area at a desired frequency and in a desired pattern, excitation of the waveguide by the actuator causing the optical component to rotate without substantial lateral displacement, so as to scan a region with light exiting the optical component.

22. The method of Claim 21, wherein the step of substantially reducing a cross-sectional area of a portion of the waveguide comprises the step of immersing the waveguide in a multi-layer etching apparatus that includes an etchant layer of a liquid selected for its ability to etch away material comprising the waveguide to reduce the cross-sectional area of the waveguide when the waveguide is exposed to the etchant layer.

23. The method of Claim 22, wherein the multi-layer etchant apparatus includes a solvent layer disposed above the etchant layer and an etch-stop layer disposed below the etchant layer, said optical component being immersed within said etch-stop layer when the portion of the waveguide is immersed in the etchant layer to reduce the cross-sectional area of said portion of the waveguide.

24. The method of Claim 23, wherein the solvent layer prevents vapors from the etchant layer from attacking the waveguide above the etchant layer.

25. The method of Claim 23, wherein the etch-stop layer comprises a fluorinated oil that stops the liquid of the etchant layer from etching away the material comprising the waveguide and the optical component, once the waveguide and optical component are immersed within the etch-stop layer.

26. The method of Claim 21, wherein the etchant layer comprises hydrofluoric acid.

27. The method of Claim 21, wherein the step of attaching the optical component to the distal end of the waveguide comprises the step of fusing the optical component to the waveguide by employing a source of energy to heat the distal end of the waveguide.

28. The method of Claim 21, wherein the optical component comprises a drum lens, further comprising the step of modifying a distal surface of the drum lens to optically focus light exiting the optical component so that the light travels in one of a substantially collimated path and a converging path.

29. The method of Claim 21, further comprising the step of providing one of a ball lens, a drum lens, a graded index (GRIN) lens, and a diffractive optical element as the optical component attached to the distal end of the waveguide.

30. The method of Claim 21, wherein the step of substantially reducing the cross-sectional area of the waveguide comprises the step of selecting dimensions of said portion and of a part of the waveguide that is adjacent to and distal of said portion, to ensure that a vibratory node of waveguide, when driven into vibration by the actuator, is substantially coincident with the back focal plane of the optical component.

31. The method of Claim 21, wherein the optical component includes a back focal plane, and wherein the waveguide includes an effective light source at a position adjacent to the distal end of the waveguide where the waveguide has substantially reduced wave guiding capability, said step of attaching the optical component comprising the step of positioning the effective light source substantially coincident with the back focal plane of the optical component.

32. The method of Claim 21, wherein the optical component includes a back focal plane, and wherein the waveguide includes an effective light source at a position adjacent to the distal end of the waveguide where the waveguide has substantially reduced wave guiding capability, said step of attaching the optical component comprising the step of positioning the effective light source proximal to the back focal plane of the optical component.

33. The method of Claim 21, wherein the step of attaching the optical component to the distal end of the waveguide substantially reduces a wave guiding capability of the waveguide at an effective light source position, said effective light source position being substantially coincident with the vibratory node of the waveguide.

34. The method of Claim 33, further comprising the step of providing an axial actuator for axially moving the waveguide in synchrony with the vibration of the waveguide so as to compensate for a variation in an axial position of the effective light source position of the light conveyed by the waveguide caused by a deflection of the portion of the waveguide that is reduced in cross-sectional area.

35. The method of Claim 21, wherein the step of substantially reducing the cross-sectional area of a portion of the waveguide adjacent to the distal end comprises the step of forming a desired non-linear shape for the waveguide in the portion where the cross-sectional area is substantially reduced.

36. A method for scanning a region with light conveyed through a waveguide between a proximal end and a distal end of the waveguide, the distal end of the waveguide having an effective light source and a cantilevered portion, with an optical component being attached to the distal end of the waveguide, comprising the steps of:

(a) actuating the cantilevered portion of the waveguide to vibrate at a desired frequency and in a desired pattern; and

(b) controlling a dimensional configuration of the waveguide so as to position the effective light source in a desired relationship relative to a vibratory node of the waveguide, said optical component being thereby caused to rotate when the cantilevered portion of the waveguide is vibrating, so that light exiting the optical component scans the region.

37. The method of Claim 36, further comprising the step of translating a distal end of the cantilevered portion of the waveguide so that the light exiting the optical component scans the region due to both the rotation and the translation of the optical component.

38. The method of Claim 36, further comprising the step of providing an additional scan lens disposed between the region and the optical component for optically modifying the light exiting the optical component before the light thus modified is incident on the region.

39. The method of Claim 36, wherein the step of controlling the dimensional configuration of the waveguide comprises the step of positioning the effective light source substantially coincident with the vibratory node of the waveguide.

40. The method of Claim 36, wherein the effective light source is disposed adjacent to the distal end of the waveguide where the waveguide ceases to guide light propagated through the waveguide, and wherein the step of controlling the dimensional configuration comprises the step of selectively positioning the effective light source for the light substantially coincident with both a back focal plane of the optical component and the vibratory node of the waveguide.

41. The method of Claim 36, wherein the effective light source is disposed adjacent to the distal end of the waveguide where the waveguide ceases to guide light propagated through the waveguide, and wherein the step of controlling the dimensional configuration comprises the step of selectively positioning the effective light source for the light more proximal, relative to a back focal plane of the optical component.

42. The method of Claim 36, further comprising the step of moving the waveguide axially in synchrony with the vibration of the waveguide to compensate for an axial movement of a position of the effective light source of the light relative to the vibratory node caused by a deflection of the portion of the waveguide that is vibrating.

43. The method of Claim 36, further comprising the step of axially offsetting a position of the effective light source relative to the vibratory node to at least reduce a lateral displacement of the position of the effective light source relative to the vibratory node caused by a deflection of the portion of the waveguide that is vibrating.

44. The method of Claim 36, wherein the step of controlling the dimensional configuration of the waveguide comprises the step of reducing a cross-sectional area of the portion of the waveguide that is cantilevered, over a predefined length and by a predefined radial dimension.

45. The method of Claim 36, wherein the step of controlling the dimensional configuration of the waveguide comprises the step of reducing a cross-sectional area of the portion of the waveguide that is cantilevered, to form said portion of the waveguide in a non-linear shape.

46. The method of Claim 36, wherein the optical component has a back focal point, and wherein the step of controlling the dimensional configuration of the waveguide comprises the step of coupling the optical component to the distal end of the waveguide with a spacer of a longitudinal dimension selected to ensure that the back focal point of the optical component is substantially coincident with the vibratory node of the waveguide.

47. The method of Claim 36, wherein the desired scan pattern causes the optical component to scan the region in one of a rectilinear, raster, circular, spiral, rotating linear, propeller, and Lissajous pattern.

48. The method of Claim 36, wherein the optical component comprises one of a ball lens, a drum lens, a graded index (GRIN) lens, and a diffractive optical element.